RESEARCH DEPARTMENT

The effect of registration errors in three-tube and four-tube colour television cameras

RESEARCH REPORT No. PH-11

UDC 621.397.61 : 621.397.132
1967/47

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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Research Report No. PH-11, Serial No. 1967/47

THE EFFECT OF REGISTRATION ERRORS IN THREE-TUBE AND FOUR-TUBE COLOUR TELEVISION CAMERAS

The sharpness of the pictures obtained from a three-tube colour television camera is very sensitive to the presence of errors of registration, that is, the superimposition of the three colour-separation pictures. One of the principal advantages of the four-tube camera is a reduced sensitivity to such errors because of the generation of a high-definition luminance signal independently of the colouring information. Nevertheless colour fringing is produced in a four-tube camera when misregistration of the colouring signals is present, and it is even possible for the sharpness of the picture to be affected to a certain extent. The severity of the latter effect is however much less than in the case of a comparable registration error in a three-tube camera.

The purpose of the work was to assess the subjective visibility of loss of sharpness and of colour fringing for various degrees of registration error in each channel of both three- and four-tube cameras; the effect on the compatible monochrome picture was also examined. The results of the tests are used to define permissible tolerances in the relative position of the images obtained from each channel. It is found that for both types of camera the most severe loss of picture quality for a given error in registration occurs when the error is present in the green channel. It is also shown that the use of the Philips 'contours-out-of-green' technique in a three-tube camera does not permit relaxation of the appropriate tolerance; however, the impairment resulting from gross registration errors, falling outside the specified tolerance, is reduced to a certain extent by the use of this technique.

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SUMMARY

The subjective effect of errors in registration occurring in three- and four-tube colour television cameras were determined by using simulations of camera signal-processing chains in conjunction with a high-quality flying-spot slide scanner. Precise registration is required in both classes of camera, but the three-tube camera is more sensitive to registration errors because of the loss of sharpness which results from the formation of the luminance signal from misregistered components during the coding process.

1. INTRODUCTION

The red, green and blue colour-separation signals* generated by a three-tube colour television camera are combined, as part of the coding process, to form a luminance signal according to the equation

$$E_Y' = 0{\cdot}3E_R{}^{1/\gamma} + 0{\cdot}59E_G{}^{1/\gamma} + 0{\cdot}11E_B{}^{1/\gamma} \qquad (1)$$

In all cases except fully-saturated colours all three colour-separation signals contribute to form the luminance signal; the fine-detail information in the luminance signal, which determines the subjective sharpness of both the colour and compatible received pictures, is therefore derived from corresponding fine-detail information in all three colour-separation signals. The presence of a registration error (that is, a spatial lack of superimposition between the three colour-separation pictures) will give rise to a loss of time-coincidence between the fine-detail information occurring in each colour-separation signal. In the case of severe registration errors this will appear as ghost-image effects in the displayed picture; for smaller errors it will be seen as a loss of sharpness. For all but the smallest registration errors, these effects are likely to be accompanied, in the colour picture, by the appearance of colour fringes on edges. No loss of sharpness can occur in the luminance signal when it is obtained directly from a separate full-bandwidth channel, as in the case of a four-tube camera, although colour fringing effects may still be produced by registration errors between the four tubes. It is, however, possible that the introduction into the luminance signal of misregistered picture information carried by the low-bandwidth colouring signals, during the 'delta-L' correction process[1], could affect the sharpness of this signal slightly.

The effects of misregistration in a three-tube camera may be influenced by the 'contours-out-of-green' technique introduced by Philips[2]. Instead of aperture-correcting each colour-separation signal individually, a contour signal (that is, a signal having components suitable for both vertical and horizontal aperture-correction) is derived from the green colour-separation signal and used for the correction of all three colour-separation signals. The fine-detail information in the luminance signal therefore comes to an increased extent from one colour-separation signal only, thus reducing the loss of picture-sharpness due to misregistration effects.

Evaluation of registration errors in colour television cameras must include assessments of both colour fringing effects and also the loss of sharpness produced by the misregistration of each channel. Picture-originating equipment which is inherently immune from misregistration effects is required for such a test and for this reason a high-quality flying-spot slide scanner was used to generate the colour-separation signals. Registration errors were introduced by inserting known time delays into the relevant signal paths, and the results of the tests are quoted in terms of these timing errors. The duration of an active scanning line in the 625-line television standard is 52μs; thus, for example, a timing error of 50 ns is equivalent to a spatial registration error of nearly 0·1% of the picture width.

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* In this report the term 'colour-separation signal' will be used to denote a signal having the full system bandwidth (as in a 3-tube camera) and the term 'colouring signal' will be used when referring to a narrow-bandwidth signal as obtained from the red, green and blue channels in a 4-tube camera. The term 'colour signal' will be used in the general case, and will refer to both classes of signal.

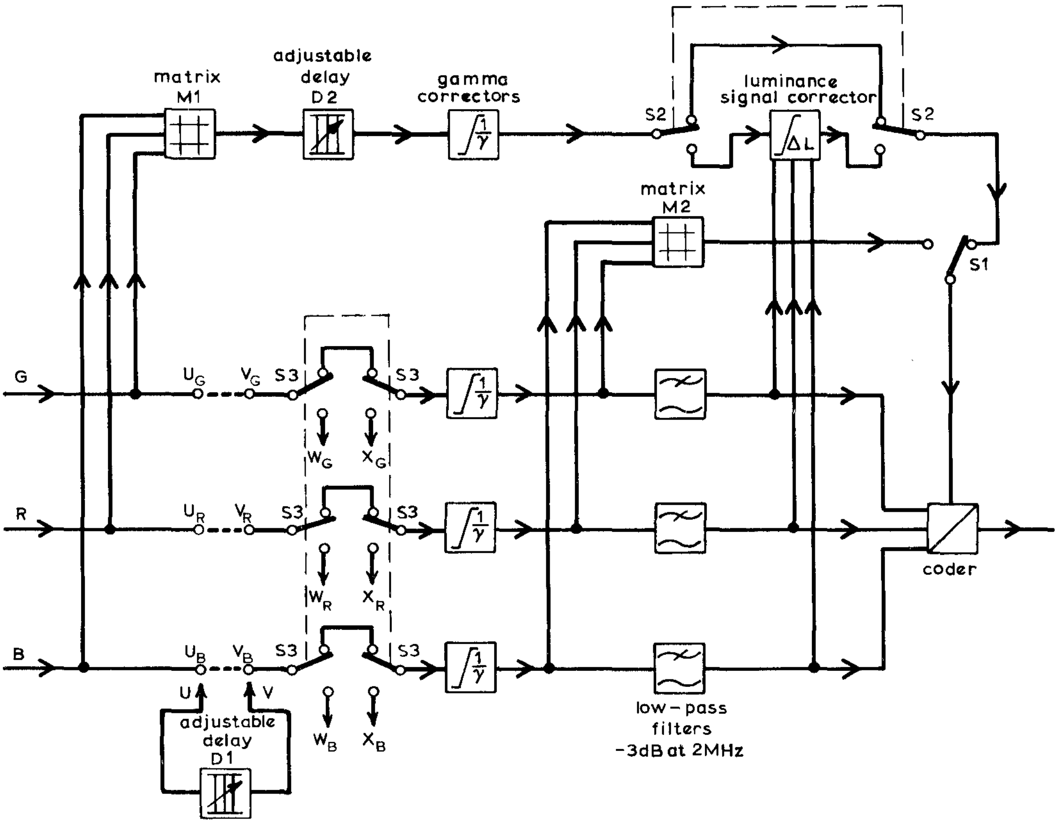

Fig. 1 - Block diagram of camera simulation equipment

Electronic masking was used to increase the colour-saturation to a value comparable with the normal performance of colour cameras.

2. EXPERIMENTAL DETAILS

2.1. Equipment Arrangements

Fig. 1 shows details of the equipment arrangement used to simulate registration errors in three- and four-tube colour cameras. Two basic luminance signals were generated. Matrix M1 combined the linear colour-separation signals from the slide scanner (using the conventional matrix constants shown in Equation (1)) and generated a signal equivalent to the linear output of the separate-luminance tube of a four-tube camera; this luminance signal was passed through a gamma-correcting amplifier before coding*. Matrix M2 similarly combined the gamma-corrected colour-separation signals and thus generated a conventional NTSC luminance signal, such as would be obtained by the use of a three-tube camera. Either of these luminance signals could be selected by means of the switch S1 and passed to the coder, which had been arranged to accept an external luminance-signal input. 'Delta-L' luminance-signal correction could be applied to the four-tube camera luminance signal using a multi-linear matrix circuit[3]; this facility was selected by the switch S2.

As well as supplying matrix M2, the gamma-corrected colour-separation signals were used to generate the chrominance signals E_I and E_Q and also to provide luminance-signal correction if required. In this connection it may be noted that the components of the chrominance signal were always of the form $(E_R{}^{1/\gamma} - E_Y')$ and $(E_B{}^{1/\gamma} - E_Y')$ and thus, in the case of the four-tube camera simulation, corresponded with the 'Livingston' system of coding[1]. In a four-tube camera the colouring channels have a relatively narrow bandwidth, and the 2 MHz low-pass filters were inserted to simulate this bandwidth restriction.

The effect of a registration error in one of the colour-separation signals could be simulated by the introduction of a calibrated delay D1 between the points U and V in the appropriate signal path. Because of the delay introduced by the 2 MHz low-pass filters an additional delay was required in the separate-luminance signal path. The delay D2 provided for this purpose was made variable so that the separate-luminance signal could be either advanced or retarded in time relative to the colour signals. The results given for the effects of luminance-signal misregistration in Section 3 are the mean of the results obtained under these two conditions, thus minimizing the effect of any residual timing errors between the luminance and colour signals that might have been present in the coder.

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* For convenience NTSC coding was used throughout the tests, but the results are equally applicable to the PAL system.

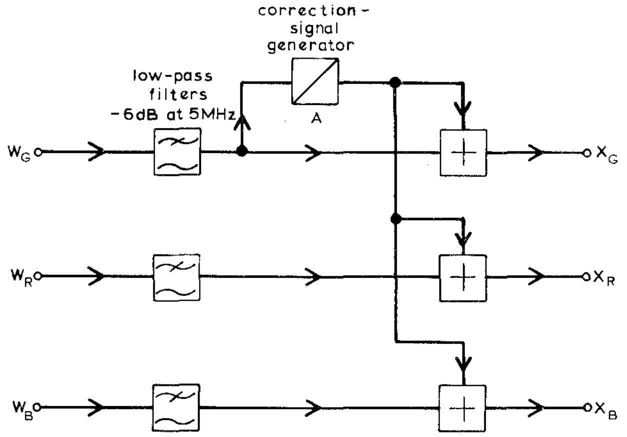

Fig. 2 - Block diagram of 'contours-out-of-green' simulation equipment

The equipment used to simulate the 'contours-out-of-green' signal-processing technique was connected between points W and X in Fig. 1. Low-pass filters, introducing a loss of 6 dB at 5 MHz, were placed in each colour-separation signal (Fig. 2) to simulate the unequalized outputs of a three-tube camera using plumbicon camera-tubes. The output of the correction-signal generator A was arranged to give accurate horizontal aperture-correction of the green colour-separation signal when the two signals were added together before being returned to the remainder of the three-tube camera simulation equipment at the point X_G (Figs. 1 and 2). This same correction signal was also added to the red and blue colour-separation signals before their return at points X_R and X_B to the processing chain. Selection of the contours-out-of-green simulation was controlled by the switch S3 (Fig. 1). Because the deliberate errors in registration were introduced by means of small timing errors between the colour-separation signals they occurred only in the horizontal direction; the contours-out-of-green technique was therefore arranged to be effective only in this direction. The correction signal did not provide any vertical aperture-correction, and the slide-scanner resolution in a vertical direction was not reduced below its normal high standard.

2.2. Test Procedure

Groups of observers were seated at distances of between four and six times picture height from the display monitors. Before each session the picture material was shown unimpaired and an extreme example of impairment was also demonstrated. The observers were asked to assess picture impairment according to the scale shown in Table 1. In all cases the registration error was introduced into one channel at a time, the other channels remaining in their correct time relationship.

TABLE 1

Scale of Picture Impairments

Description of Impairment	Score
Imperceptible	1
Just Perceptible	2
Definitely perceptible but not disturbing	3
Somewhat objectionable	4
Definitely objectionable	5
Unusable	6

An average of about 36 different test conditions were presented in random order during each session of tests. The picture highlight brightness was 51 candela/m^2 (15 ft-Lamberts) and only sufficient ambient light was provided for the observers to record their score. The picture material consisted of three slides:

Ski Couple (E.B.U. 2)
Cocktail Bar (E.B.U. 5)
Kitchen Scene (E.B.U. 6)

Altogether some 34 observers took part in the tests and a total of about 2,800 separate assessments were returned.

3. DISCUSSION OF RESULTS

3.1. Misregistration of the Luminance Signal

The effect of misregistration of the luminance signal on the visibility of colour fringing in the decoded colour picture is shown in Fig. 3. The

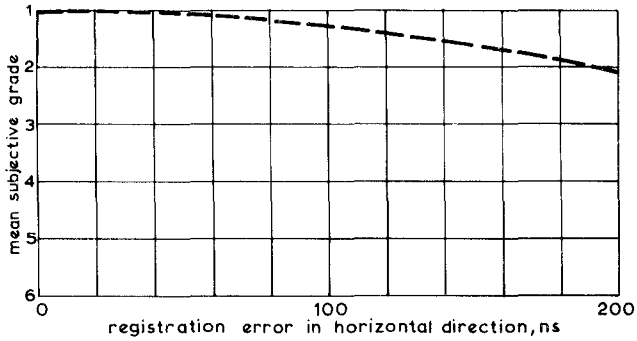

Fig. 3 - The visibility of colour fringing in the decoded colour picture produced by a registration error in the luminance channel of a four-tube camera

use of Delta-L luminance signal correction in the four-tube camera simulation had no significant effect at the viewing distances used during the tests and the curves are applicable to both cases. It can be seen from Fig. 3 that the colour picture is insensitive to this form of misregistration, an error of 200 ns (2 picture elements or about 0·4% of the picture width) giving rise to an increase in impairment visibility of only one subjective grade.

In the case of the compatible picture the effect of a luminance misregistration of up to 200 ns produces no significant picture impairment. The effect of misregistration of the luminance signal is to introduce a spatial error between the luminance outline of a coloured object and the corresponding colour-subcarrier pattern; the presence of this error was not apparent at the viewing distances used during the tests, although it could be seen by close inspection of the displayed picture.

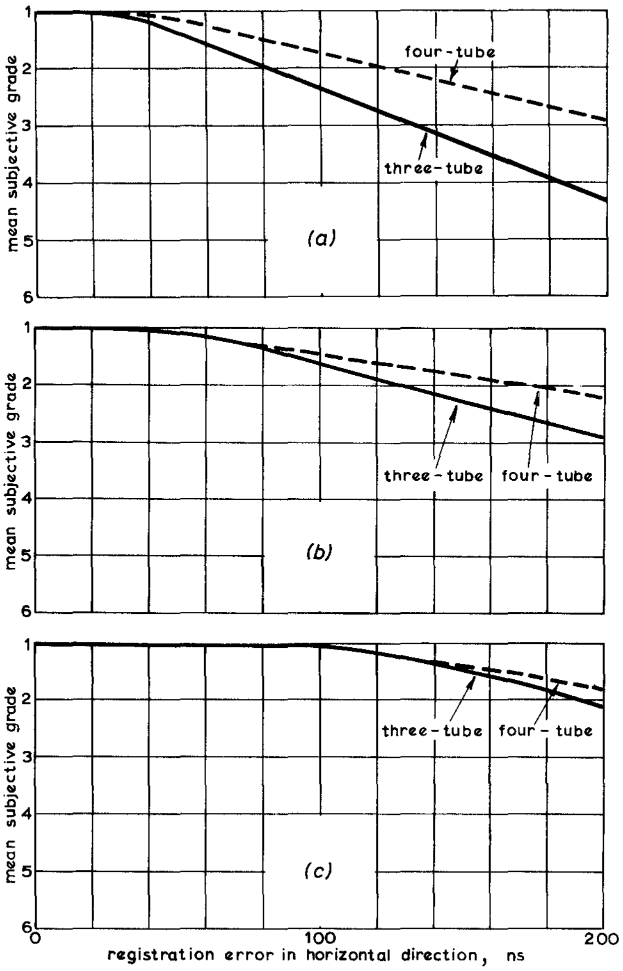

Fig. 4 - The visibility of colour fringing in the decoded colour picture produced by a registration error in one colour channel

(a) Green channel misregistered
(b) Red channel misregistered
(c) Blue channel misregistered

3.2. Misregistration of a Colour Signal

Figs. 4 and 5 show respectively the visibility of colour fringing and the subjective lack of sharpness of the colour display when one colour signal is misregistered with respect to the others. As in the case discussed in Section 3.1, no significant difference was found between the results obtained for the four-tube camera with and without the 'Delta-L' luminance-signal correction applied to the luminance signal.

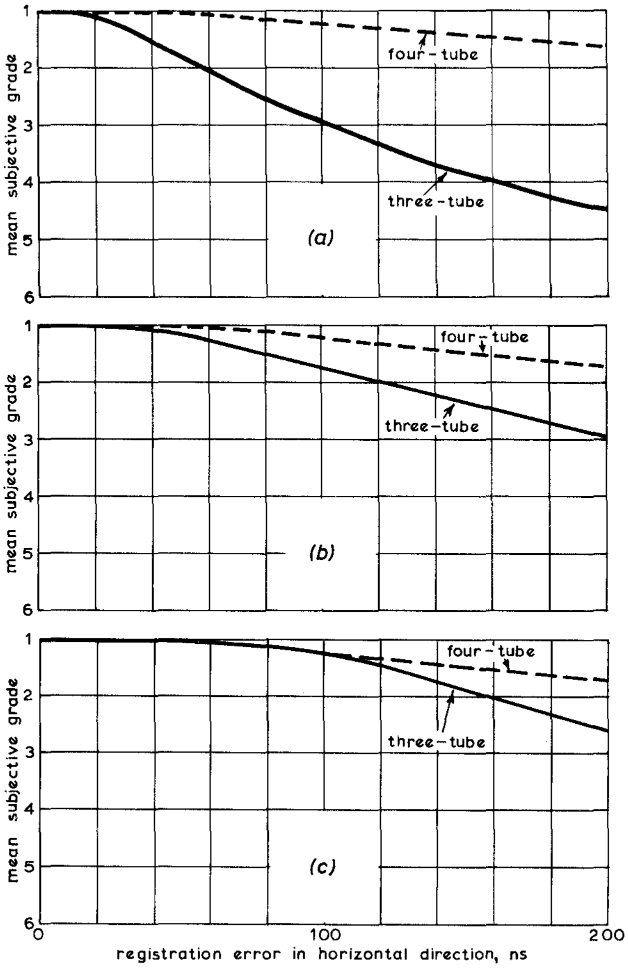

Fig. 5 - The loss of sharpness of the decoded colour picture produced by a registration error in one colour channel

(a) Green channel misregistered
(b) Red channel misregistered
(c) Blue channel misregistered

The visibility of colour fringing (Fig. 4) was found to be very dependent on which colour signal was misregistered, green being always the worst case and blue the best case. This can be explained in terms of the luminosity coefficients of the primary colours; thus a much more obvious colour fringe will be produced if the green image (luminosity coefficient 0·59*) is displaced than if the blue image (luminosity coefficient 0·11*) is displaced, while the visibility of the colour fringe produced by displacement of the red image (luminosity coefficient 0·30*) will be between these two extremes. It may also be observed that for small registration errors there is no significant difference in the visibility of colour fringing for three-tube and four-tube cameras, although for a large error the three-tube camera gives rise to more visible colour fringing than the four-tube camera. This is probably because the colour fringing produced by a three-tube camera has both a luminance and a colorimetric effect on the displayed picture, and thus has greater visibility for a given error of registration. The subjective sharpness of the colour picture (Fig. 5) and the overall impairment of the compatible picture (Fig. 6) from a three-tube camera are both markedly dependent on the particular colour-separation signal that is misregistered. This is because the loss of picture sharpness depends, for a given registration error, on the relative levels of 'correct' and 'misregistered' components in the luminance signal. When the green channel is misregistered the proportions are 0·41 : 0·59, while an error in the blue channel will introduce only a relatively small misregistered component.

Fig. 6 shows that, in the case of the four-tube camera, the presence of a registration error in the colouring signals has no significant effect on the compatible picture, whether or not the luminance-signal correction is applied to the luminance signal. In the case of the colour picture (Fig. 5), the picture sharpness was affected to a small extent by misregistration of the colouring signal: the degree of impairment did not depend on which colouring signal was misregistered, and was probably due to the appearance of the colour-fringes which tended to reduce the subjective sharpness of

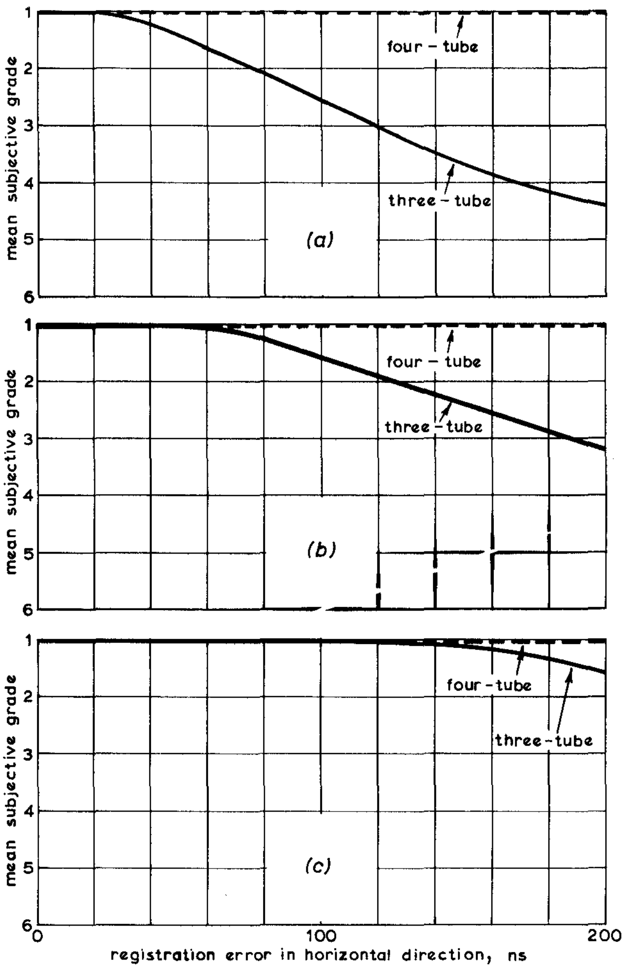

Fig. 6 - The overall impairment of the compatible picture produced by a registration error in one colour channel

(*a*) Green channel misregistered
(*b*) Red channel misregistered
(*c*) Blue channel misregistered

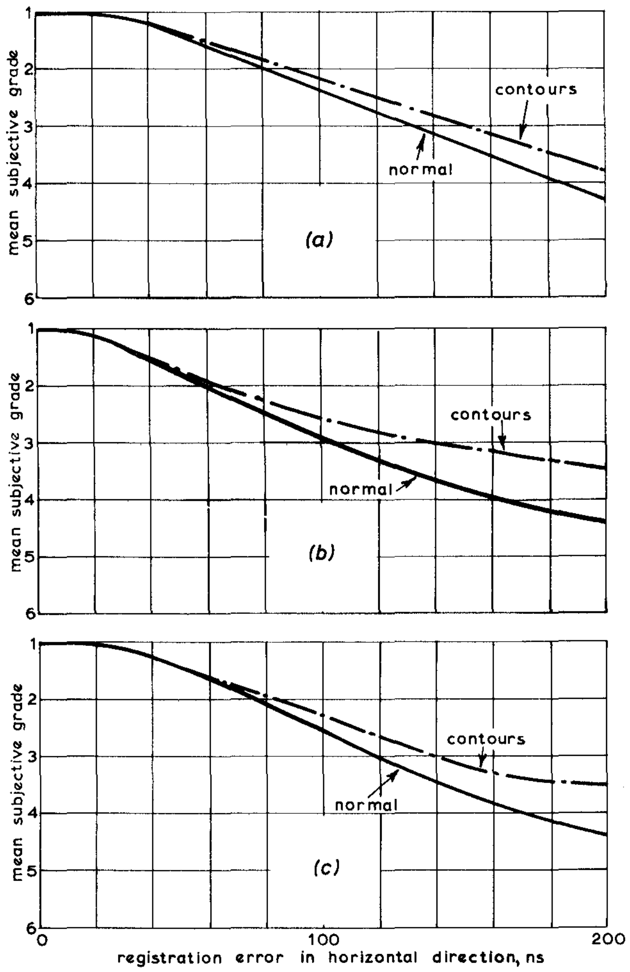

Fig. 7 - The effect of a registration error in the green channel of a three-tube camera using contours-out-of-green correction

(*a*) Visibility of colour fringing in decoded colour picture
(*b*) Loss of sharpness of decoded colour picture
(*c*) Overall impairment of compatible picture

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* Assuming optical colour analysis for NTSC phosphors.

the picture.

3.3. The Effect of Using 'Contours-out-of-Green' Correction

Fig. 7 shows the picture impairments obtained when a registration error was introduced into the green channel of a simulation of a three-tube camera using contours-out-of-green correction; for comparison, the results obtained for conventional three-tube camera operation are also shown. It can be seen that the use of contours-out-of-green correction reduced the impairment for relatively large registration errors, but this benefit diminished as the registration error decreased. By comparing Fig. 7 with Figs. 4(*a*), 5(*a*) and 6(*a*), it can be seen that contours-out-of-green correction does not confer as great a reduction in picture impairment as the use of the four-tube camera configuration. Greater immunity to green-channel registration errors would almost certainly be obtained by a deliberate restriction of bandwidths of the red and blue colour-separation signals, so that a greater proportion of the fine-detail information in the luminance signal was derived only from the green colour-separation signals; at the same time, these measures would make the sharpness of the received picture, in the absence of registration errors, much more dependent on the presence or absence of green fine-detail information in the transmitted scene. The present technique of simply making good the aperture losses of all three camera tubes by means of fine-detail information from the green channel seems to be a reasonable compromise.

The reduction in the visibility of colour fringing by the use of the contours-out-of-green technique (Fig. 7(*a*)) is a consequence of the reduction of loss of sharpness for a given registration error (Fig. 7(*b*)); this interdependence of the two difference types of picture impairment has been discussed in Section 3.1.

4. THE TOLERANCE TO REGISTRATION ERRORS IN A COLOUR TELEVISION CAMERA

The tolerance to registration errors in a colour television camera must be governed by the worst subjective effects that these errors can produce. It is therefore apparent that, in the case of a three-tube camera, account must be taken of the impairment of subjective sharpness of the colour and compatible pictures when the registration error occurs in the green colour channel (Figs. 5(*a*) and 6(*a*)). In the case of a four-tube camera, however, the impairment due to colour fringing in the colour picture is most important, again when the registration error is in the green channel (Fig. 4(*a*)). A tolerance must also be stated for registration errors occurring in the luminance channel (Fig. 3). A criterion often adopted for placing a limit on a cause of picture impairment is to specify that the impairment shall not exceed the 'limit of perceptibility' corresponding to grade 1·5 (i.e. on average half of the observers are able to see the impairment and half not). Using this criterion the following maximum values of registration error are obtained:-

For a three-tube camera: 36 ns

For a colouring channel of a four-tube camera: 80 ns

For the luminance channel of a four-tube camera: 140 ns

It should however be noted that the visibility of the picture impairment increases more rapidly with increase of registration error than these figures at first suggest: for example, an impairment of grade 2 is brought about by a further increase in registration error of only 20 ns in the case of the three-tube camera, the corresponding values for the colouring and luminance channels of a four-tube camera being 40 ns and 60 ns respectively. It is therefore suggested that a rather more stringent control of registration error should be exercised than is given by the 'grade 1·5' criterion, and the following tolerances can be suggested for important zones of the picture:-

(a) For a three-tube camera, the error in registration must not exceed 25 ns (0·05% picture width).

(b) For a four-tube camera, the errors in registration must not exceed:

(i) 50 ns (0·1% picture width) in a colouring signal;

and (ii) 100 ns (0·2% picture width) in the luminance signal*.

Although these tolerances have been derived experimentally by means of horizontal picture displacements using time-delays, there seems to be no reason why they should not be applicable to an equivalent degree of misregistration in any direction.

Inspection of Fig. 7(*b*) shows that the use of the 'contours-out-of-green' technique, as described in Section 3.3, does not permit the relaxation of the tolerance on registration error given above for a three-tube camera.

5. CONCLUSIONS

The colour picture displays obtained from both three-tube and four-tube television cameras are particularly sensitive to registration errors occurring in the green channel. In a three-tube camera, the most noticeable picture impairment is a loss of subjective sharpness, and to avoid this the registration error in this channel should not exceed 25 ns (0·05% of the picture width). The use of the contours-out-of-green aperture-correction technique does not reduce the effect of small green-channel registration errors although larger errors are mitigated to some extent. For a four-tube camera, colour fringing is the most noticeable impairment and for this reason the registration error in the green channel should not exceed 50 ns (0·1% of the picture width). The edge-effects produced by registration errors in the luminance channel of a four-tube camera are not significant for errors less than 100 ns (0·2% of the picture width).

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* Errors of coincidence between luminance and chrominance signals may also be incurred in line transmissions, propagation and reception. The figure of 100 ns is an overall tolerance: it has been suggested that only half this (50 ns) should be allowed in the camera specification.

A registration error in the red colour-signal channel gives rise to less impairment than the same registration error in the green channel; still less picture impairment is produced by a registration error in the blue channel.

The compatible picture obtained from a three-tube camera is impaired to about the same extent as the colour picture; however registration errors of up to 200 ns (1/200 of the picture width) have no significant effect on the compatible picture obtained from a four-tube camera.

The presence or absence of the 'Delta-L' correcting signal does not significantly affect the performance of the four-tube camera as far as registration errors are concerned.

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Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey